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clearly and certainly the occurrence of all the conditions required for the union of the two pieces of ice under my theory. The contingent occurrence of the additional conditions now specially brought forward, was indeed from the first somewhat familiar to my mind, but was left out of the explanation as being unessential and not perhaps quite so clearly apparent. Their occurrence has, however, now become essential to the explanation of Prof. Faraday's new experiments:—and by it I consider these are shown not to militate against my general theory of the plasticity of ice, but to corroborate it strongly, and to confirm its application to the various observed cases of the union of two pieces of moist ice when placed in contact.

May 16, 1861.

Major-General SABINE, R.A., Treasurer and Vice-President,
in the Chair.

Sir Andrew Scott Waugh was admitted into the Society.

The CROONIAN LECTURE was then delivered by C. E. BROWN-SÉQUARD, M.D., F.R.S., “On the Relations between Muscular Irritability, Cadaveric Rigidity, and Putrefaction.”

The object of this lecture is chiefly to try to establish the following law:—*The greater the degree of muscular irritability at the time of death, the later the cadaveric rigidity sets in and the longer it lasts, and the later also putrefaction appears and the slower it progresses.*

Many physiologists have already shown that in certain cases cadaveric rigidity appears late and lasts long when muscular irritability is powerful at the time of death; but the great generality of this result and its prevalence as a law, had not been established, nor had the general relation of these conditions of the muscular system to putrefaction, as stated in the above law, been enunciated before my first researches on this subject*.

* In 1849 and 1850 I published a summary of some experiments the object of which was to prove the existence of the above law. In a paper read at the Académie des Sciences of Paris, and in 1857, I related some new experiments

The law I wish to establish is borne out by a great many facts, observed in the lower animals and in man, showing that every cause of increase in the degree of muscular irritability a short time before death, may be considered as a cause of delay of the setting in of cadaveric rigidity and of the persistence of that *post-mortem* state of muscles, and also a cause of delay of the time at which putrefaction manifests itself in muscles, and an evident slowness of the process of putrefaction; while, on the contrary, every cause of decrease in the degree of muscular irritability some time before death, produces the opposite effect on cadaveric rigidity and putrefaction.

I will examine successively the relations existing between muscular irritability, *post-mortem* rigidity and putrefaction in the various following cases:—1st, in paralysed muscles; 2nd, in muscles the temperature of which is diminished before death; 3rd, in animals or men killed by lightning or by galvanism; 4th, in over-driven cattle, in cocks after a fight, in men after over-exertion, and in animals hunted to death; 5th, in men dying in a good state of health or after prolonged disease; 6th, in men who have died of cholera, of tetanus, or after other convulsive diseases; 7th, in men and animals killed by poison.

1st. *Irritability, cadaveric rigidity and putrefaction in paralysed muscles.*—I have shown long ago† that during a certain period after the beginning of a paralysis, the paralysed muscles are endowed with more irritability than healthy muscles. I have ascertained this fact in various ways; but the most decisive method consists in comparing the duration of irritability in a paralysed muscle and in the corresponding healthy one of the opposite side, while they are both submitted to the same excitation. I have often found in experimenting in that way, that the paralysed muscle remained irritable twice, three times, or even four times as long as the healthy one.

The following experiments, taken out of many of the same kind, while they show that muscular irritability is increased in consequence

having the same bearing. (See *Comptes Rendus de la Soc. de Biologie*, vol. i. 1849, pp. 39, 138, 154 and 173, and vol. ii. 1850, p. 194; also *Comptes Rendus de l'Acad. des Sciences*, vol. xlv. 5th Oct. 1857.)

† *Experimental Researches applied to Physiology and Pathology*. New York, 1853, pp. 68–73.

of paralysis, show also that in such conditions cadaveric rigidity sets in late and lasts long, and that putrefaction also appears late and progresses slowly.

(1) In the muscles of the leg of a dog, paralysed by section of the roots of the sciatic nerve, on one side, in the spinal canal, there was an excessive irritability at the time of death (by asphyxia), five hours after the section of the nerve-roots. In the paralysed muscles irritability lasted ten hours; cadaveric rigidity appeared nearly at the time of the cessation of irritability*, and lasted nearly thirteen days†. Putrefaction was evident only on the beginning of the fifteenth day, and it was not very much advanced on the seventeenth day. In the healthy leg muscular irritability lasted but four hours, and was, as usual, at once followed by some degree of cadaveric rigidity. During nearly five days this rigidity lasted, and putrefaction was evident as soon as the sixth day, and much advanced on the seventh, at a time when the paralysed limb was still perfectly rigid. The temperature of the room during the fortnight the experiment lasted ranged between 6° and 11° Cent. (42°·8 to 51°·8 Fahr.) The following shows at a glance the differences between the two legs:—

	Durat. of irrit.	Durat. of cad. rigid.	Advanced putref.
Paralysed muscles . .	10 hours.	13 days.	17th day.
Healthy muscles . . .	4 hours.	5 days.	7th day.

(2) I have found that muscular irritability is very much increased in the paralysed limb of an animal on which a lateral half of the spinal cord has been divided transversely in the dorsal region. In this case, as well as after paralysis from section of a nerve, cadaveric rigidity sets in later and lasts longer, and putrefaction appears later, and proceeds slower in the paralysed hind leg (on the side of the section of the cord) than in the other.

(3) A month after the section of a nerve we have another kind of verification of the law: irritability is then diminished in the paralysed muscles; and we find that cadaveric rigidity sets in sooner and

* Usually some muscles or some parts of a muscle are already rigid while irritability still remains in other parts. This was the case in a marked manner in the above experiment, especially in the paralysed leg.

† In dogs, cadaveric rigidity lasts longer than in most other animals. I have seen it lasting twenty-six days in a healthy dog killed by asphyxia in midwinter in Paris.

lasts a less time ; and that putrefaction appears sooner and proceeds quicker in them than in the healthy muscles.

2nd. *Influence of a diminution of temperature of muscles before death upon their irritability, cadaveric rigidity, and putrefaction.*—I found many years ago that all the vital properties of the nervous centres, the nerves and the muscles, in adult as well as in young warm-blooded animals, may be much increased in consequence of a diminution of temperature of these organs. The following experiments show that when muscular irritability is increased by that cause, the increase has the same influence upon cadaveric rigidity and putrefaction as when it is caused by paralysis.

In two kittens three days old, and of the same litter, I found after death (by asphyxia) the following differences : one of them had the temperature of 37° Cent. (98°·6 Fahr.) in the rectum at the time of death ; its muscular irritability in the posterior limbs gave way to cadaveric rigidity 3½ hours after the last effort at breathing ; this rigidity lasted nearly three days ; putrefaction began to be evident on the fourth day after death, and was much advanced the next day ; while in the other, the temperature of which was only 25° Cent. (77° Fahr.) at the time of death, muscular irritability lasted more than nine hours after the last breathing ; cadaveric rigidity began during the tenth hour and lasted nine days ; and putrefaction, which began on the tenth day, was not much advanced until two days later.

In many other instances of newly-born cats, dogs, rabbits, and birds (especially ravens, sparrow-hawks, jays, and magpies), I have observed similar differences as those observed in the preceding experiment, when I noticed the duration of irritability after death and its relations to cadaveric rigidity and putrefaction, according to the degree of animal heat at the time of death. As a general rule, when there was a difference of 8° or 10° Cent. (14° to 18° Fahr.) in the temperature of two animals of the same age and the same species, muscular irritability and cadaveric rigidity lasted twice or three times longer in the cooler animal than in the other, and putrefaction in the former was much less rapid.

I have observed the same differences also in adult birds and mammals*. It is thus clearly shown by experiment that when the

* For the means of diminishing the temperature of warm-blooded animals, see my Researches on Asphyxia (Journal de Physiol. Jan. 1859).

temperature of muscles is diminished before death, their irritability lasts long after death, cadaveric rigidity sets in late and lasts long, and putrefaction appears late and proceeds slowly.

3rd. *Influence of death by lightning and galvanism on cadaveric rigidity and putrefaction.*—It is well known that J. Hunter thought that cadaveric rigidity cannot take place after death by lightning; but many facts have been recently published, showing that in animals and men killed by lightning, cadaveric rigidity has existed, and there can indeed be no doubt of its occurrence in such cases. At the same time there is reason to believe that in some instances of that mode of death cadaveric rigidity has either not set in, or has been of so short a duration, that it has not been possible to ascertain its existence. It appears difficult at first sight to reconcile facts which seem to be so much in opposition one with the other; but it will be seen that the contradiction is apparent only. Death by lightning may be the result of,—1st, a syncope by fright, or in consequence of a direct or reflex influence of lightning on the par vagum; 2ndly, hæmorrhage in or around the brain or in the lungs, the pericardium, &c.; 3rdly, concussion or some other alteration of the brain. When death by lightning is due to these causes, cadaveric rigidity may, of course, appear after death, and even last long, much in the same way indeed as when death results from these causes in persons who have not been struck by lightning. But lightning may kill in another way: it may destroy life as galvanism does, by producing such a violent convulsion of every muscle in the body that muscular irritability ceases almost at once; and the ensuing rigidity may then be of so short duration as to escape notice.

The following experiments show the powerful influence of galvanism on muscular irritability, cadaveric rigidity, and putrefaction. We will at first give the results of the galvanization of one limb:—

I. *General Result of Experiments on adult Rabbits.*

	Galvanized limb.	Limb not galvanized.
Durat. of irritability . . .	7 to 20 minutes	120 to 400 minutes.
Durat. of cad. rigidity . .	2 to 8 hours	1 to 8 days.
Putref. much advanced . .	within a day	only after several days.

II. *General Result of Experiments on adult Dogs.*

	Galvanized limb.	Limb not galvanized.
Duration of irritability	12 to 25 minutes	140 to 550 minutes.
Duration of cad. rigid.	3 to 16 hours	2 to 21 days.
Putref. much advanced .	within 30 hours	only after several days.

In experimenting on the whole body of an animal I have obtained the most striking results. I will only mention here the following experiments. Five vigorous male adult guinea-pigs were asphyxiated by the application of a ligature round the trachea, and four of them were galvanized immediately,—the first with a very powerful electromagnetic machine, the second with a weaker one, the third with a still weaker one, and the fourth by only a slight galvanic current; the fifth animal was not galvanized. In the four galvanized animals the conductors were applied one to the mouth, the other to the anus.

	Durat. of irrit.	Rigid. completed.	Durat. of rigid.
1st	4 mins.	7 mins.	15 mins.
2nd	40 mins.	60 mins.	nearly 1,200 mins. (20 hrs.)
3rd	90 mins.	120 mins.	nearly 3,600 mins. (3 days)
4th	330 mins.	420 mins.	nearly 8,600 mins. (6 days)
5th	500 mins.	600 mins.	nearly 11,500 mins. (8 days)

As regards putrefaction, it already appeared in the first animal during the first hour after death, and was much advanced the next day; its progress was slower in the four others, and successively slower in each as compared with the preceding one in the series. Considering that the power of lightning may be vastly greater than that of our galvanic machines, we can easily understand that when lightning strikes a man or an animal in the proper place, it must produce a much greater effect than galvanism, reducing the duration of irritability to a fraction of a second, and that of cadaveric rigidity in a corresponding degree, so that no trace of it remains a few minutes after death, and in like manner hastening the access of the final process of putrefaction.

The results of the application of galvanism either to separate limbs or to the whole body of animals, appear thus to show that when lightning kills without leaving any evident alteration adequate to cause death, without the subsequent appearance of cadaveric rigidity, but with early and rapid putrefaction,—the mode of action of lightning

is similar to that of galvanism, and consists in a sudden and complete exhaustion of the nervous and muscular tissues by over-action.

I have ascertained that a galvanic current passing through a rigid muscle produces no change in the duration of cadaveric rigidity, and does not in any way hasten putrefaction. It seems very probable from this negative fact that the influence of galvanism on still irritable muscles is due to the contractions then produced, and not to some direct chemical action on the muscular tissue and on the fluids which surround the muscular fibres. This probability becomes almost a certainty when we know that any cause which produces muscular contraction acts in the same way as galvanism, as we have already seen, and as will be further shown in the course of this lecture.

4th. *Influence of prolonged muscular exercise on cadaveric rigidity and putrefaction.*—It is well known that putrefaction appears very quickly in over-driven cattle and in animals hunted to death. I had the opportunity once, in September 1851, near Dinan, in France, of observing the period of setting in of cadaveric rigidity in two sheep that had been over-driven to reach a fair. They were killed by the section of the carotid arteries. In less than five minutes after death rigidity was evident in both of them, and putrefaction was manifest before the end of the day (in less than eight hours after death).

As cadaveric rigidity lasts only a short time in cocks killed during or shortly after a fight, and also in animals hunted to death, J. Hunter was led to think that it does not come on after death in such circumstances. Mr. Gulliver has shown this opinion to be erroneous. He states that fighting-cocks, as well as hares, stags, and other animals of the chase, become rigid at once after death in the circumstances referred to. It is well known that putrefaction occurs very quickly in animals hunted to death, so that every thing we know concerning over-driven cattle, cocks after a fight, or animals hunted to death, is in perfect harmony with the law that the exercise of muscular contraction diminishes muscular irritability, and that diminished irritability is followed by early cadaveric rigidity, which, in its turn, promptly gives way to a putrefaction which progresses rapidly.

A great many facts seem to show that over-exertion acts in the same way in man as in the lower animals. The accounts given of soldiers slain on the battle-field, whose body and limbs retained the

position they were in at the moment the individuals met their death, are doubtless to be explained on the supposition that, in consequence of previous excessive exertion, rigidity came on at once. In a case of a man who kept his arms extended for a long while to avoid being drowned, the arms after death were found rigid in the position they had before*. I was told by a military surgeon that putrefaction appears very soon in the corpses of soldiers killed after the over-exertion of a prolonged battle. Thus all we know concerning man seems also in harmony with the law I am endeavouring to illustrate.

5th. *Influence of nutrition of muscles on cadaveric rigidity and putrefaction.*—Nysten† has shown that when death occurs accidentally in persons in health, in whom the state of nutrition of muscles is very good, and in whom therefore these organs are endowed with a high degree of irritability, cadaveric rigidity sets in long after death and persists very long. It is so, especially, in cases of death by decapitation, strangulation, asphyxia from non-toxic gases or submersion, by sudden hæmorrhage from a wound of a large artery, &c. Nysten states that he has seen cadaveric rigidity beginning only sixteen or eighteen hours after death, and lasting six or seven days. Dr. J. A. Symonds, in an excellent article on ‘Death‡,’ states that he has seen cadaveric rigidity eight days after death by hanging. My own observations show that in the bodies of healthy persons decapitated or asphyxiated, cadaveric rigidity does not appear sooner than ten or twelve hours after death, and that it lasts more than a week when the weather is not extremely warm. In the limbs of the two decapitated men on whose bodies I made experiments on the restoration of muscular irritability by injections of blood, I found that there was some degree of irritability thirteen or fourteen hours after death, before any blood had been injected. Nysten has seen muscular irritability lasting twenty-six hours in a decapitated man, which is a fact clearly showing that cadaveric rigidity may appear only after twenty-six hours.

The reverse is seen when nutrition has been diminished for a long while before death. In a man who died at the *Hôpital du Gros-Caillou* at Paris, in the summer of 1849, cadaveric rigidity became evident within three minutes after the last breathing, and while the

* Taylor’s Manual of Med. Jurisprudence, p. 734.

† Recherches de Physiologie et de Chimie Pathol. 1811, p. 387.

‡ Cyclopædia of Anat. and Physiol. vol. i. p. 805.

heart was still beating twenty times in a minute, *i. e.* while the man was still alive, if life is considered to persist so long as the heart beats. These beatings ceased only three minutes and a half after cadaveric rigidity had shown itself everywhere. A quarter of an hour afterwards there was no more trace of cadaveric rigidity, and in less than an hour after death signs of putrefaction had appeared in the limbs. This man died of exhaustion after a prolonged typhoid fever.

It seems quite evident from the above fact, and others of the same kind which I have not mentioned, that the greatest differences exist as regards cadaveric rigidity and putrefaction in consequence of the degree of muscular irritability at the time of death.

6th. *Influence of convulsions on cadaveric rigidity and putrefaction.*—The law which it is my object to establish is borne out every day in cases in which death follows violent and prolonged convulsions. Sommer and other writers have seen cadaveric rigidity appearing so quickly after death by tetanus, that the spasmodic rigidity caused by the disease during life was followed by the *post-mortem* rigidity without any interval of muscular relaxation between these two states. In a strongly built woman, who died of hydrophobia after violent convulsions, I found that cadaveric rigidity had set in within the first hour after death, and that it ceased before the end of the tenth hour. In 1849 I made many observations at the *Gros-Caillou* Hospital in Paris, on corpses of soldiers who died from cholera, the general results of which are,—1st, that cadaveric rigidity appeared late and lasted long in those patients who died quickly, *i. e.* before a prolonged alteration of nutrition; 2nd, that those muscles which had been attacked with violent and frequent cramps, became rigid very soon after death, and remained so only a short time*.

I have often had the opportunity of seeing rabbits dying from convulsions in cases in which the supra-renal capsules were the only organs found diseased, and have often observed in them that the more violent and frequent the convulsions, the earlier did cadaveric rigidity appear, the sooner it ceased, and the quicker also putrefaction occurred and proceeded.

7th. *Influence of certain poisons on cadaveric rigidity and putre-*

* In one case cadaveric rigidity appeared in the calf of the right leg just after death, and ceased in less than two hours; while the other muscles, which had had no cramps, began to be rigid only five hours after death.

faction.—I do not intend examining any other influence of poisons except that which is due to the production of convulsions. I have made a great many experiments on this point, and the result has constantly been in harmony with the law now under consideration. The principal poisons employed were strychnine, nicotine, picrotoxine, atropia, morphia, oxalic acid, and the cyanide of mercury. I have ascertained that when death is produced almost at once by these poisons, there is hardly any effect to be observed on the time of access and duration of cadaveric rigidity and putrefaction; but when convulsions have existed for a long time before death, the influence is most remarkable. I will mention the results of but one experiment. Three dogs, as much alike as possible, and apparently in perfect health, were poisoned by the acetate of strychnine. One of them had a dose of 2 grains, another half a grain, and the third one-fourth of a grain. The first dog died at once, the second after 12 minutes, during 7 of which it had convulsions, the third after 21 minutes, during 11 of which it had convulsions.

	Durat. of musc. irrit.	Durat. of cad. rigid.	Putrefaction.
1st dog	8 hours	19 or 20 days	slow.
2nd dog	2½ „	5 days	rapid.
3rd dog	½ „	less than a day	very rapid.

In rabbits, guinea-pigs, cats and birds, as well as in dogs, I have ascertained that when they are killed by poisons causing convulsions, the more violent and the more frequent the convulsions are, the sooner cadaveric rigidity sets in and the less is the time it lasts; the sooner also does putrefaction appear, and the quicker is its progress.

I come now to the conclusion of this lecture. The facts I have mentioned show that when the degree of muscular irritability at the time of death is considerable, either in consequence of a good state of nutrition, as in persons who die in full health from an accidental cause, or in consequence of rest, as in cases of paralysis, or on account of the influence of cold, cadaveric rigidity in all these cases sets in late and lasts long, and putrefaction appears late and progresses slowly. The facts mentioned also clearly show that when the degree of muscular irritability at the time of death is slight, either in consequence of a bad state of nutrition, or of exhaustion from over-exertion, or from convulsions caused by disease or poison, cadaveric rigidity sets

in and ceases soon, and putrefaction appears and progresses quickly. The two distinct series of facts I have adduced seem, therefore, to bear out clearly the truth of the law I have endeavoured to establish on the relation between the degree of muscular irritability and the period of setting in and the duration of cadaveric rigidity, and also the time of appearance and the progress of putrefaction.

The Society then adjourned to Thursday, May 30th.

May 30, 1861.

Sir HENRY HOLLAND, Bart., V.P., in the Chair.

The reading of Dr. EDWARD SMITH's Paper "On the Elimination of Urea and Urinary Water, in their relation to the Period of the Day, Season, Exertion, Food, and other influences acting on the Cycle of the Year," was resumed and concluded.

(Abstract.)

This communication contains the result of two principal series of inquiries which have been prosecuted by the author, viz. one upon himself, extending from January 1860 to March 1861, and comprehending 336 days; and the other upon four prisoners during the month of March 1860.

The former series included the amounts of urea, chloride of sodium, and urinary water evolved daily throughout the seasons, and their relation to period of the day, season, temperature, barometric pressure, and also to the cycle of the week, excess of food, and stomach derangement. The author also ascertained the effect of fasting from solid food and of drinking water, tea, coffee, and alcohol, in the absence of breakfast and during a whole day's fast. The net weight of the body night and morning was ascertained for many weeks in the early part of 1861, and the amount of fluid and solid food was recorded during many months of the year. During these inquiries the author lived in a moderate and regular manner, but without any prescribed dietary, and spent a part of August and